SIMULATION OF PING-PONG MULTIPACTOR WITH CONTINUOUS ELECTRON SEEDING*

Moiz Siddiqi†, Rami Kishek
Institute for Research in Electronics and Applied Physics, University of Maryland, College Park

Abstract

Multipactor is a discharge resulting from secondary-electron emission. A new form of resonant multipactor combining emission from two surfaces has been studied. Initial simulations of this ping-pong mode agree with theoretical predictions of its cutoff only over a certain range. In this study, we assess the effect of the electron seeding method in the simulation on the discrepancies observed for extremely narrow and extremely wide gaps. Second, we apply techniques from non-linear dynamics to develop a new, global approach for analysing higher-periodicity multipactor. Simulation results with WARP will be discussed.

PING-PONG MULTIPACTOR THEORY

Multipactor is a discharge induced by the impact of electrons on a surface due to radio-frequency (RF) electromagnetic fields and secondary-electron emission (SEE). Depending on the impact energy and RF phase of the incident electron, a growth in the electron density is possible. Multipactor can lead to device breakdown in many applications, such as particle accelerator structures, RF systems, satellite communication equipment, and microwave components. Theoretical studies of multipactor traditionally focus on either single-surface multipactor or two-surface multipactor. A new study has been done on a combined emission from single-surface and two-surface impacts, known as ping-pong multipactor. This concept is illustrated in Figure 1. For sufficient electric fields, electrons are returned to the surface with a low impact energy [1]. These electrons can produce secondaries which then propagate to the other surface.

For small gaps between the surfaces, the ping-pong modes are found to extend the region of parameter space for multipactor growth [1]. Ping-pong multipactor is subject to the resonance condition that that the total transit time for all the impacts in one period is N RF half-periods [1]. Here, N is the order of the multipactor and is constrained to be an odd integer. Additionally, the product of SEE yields (the average number of emitted secondary electrons per incident primary electron) over one period must exceed unity for multipactor growth. It is important to note that the theory and simulation makes use of the normalized variables: $\tau = \omega t$, $\overline{x} = x/D$, $\overline{v} = v/\omega D$, $\overline{E_0} = eE_0/mD\omega^2$, for the time, position, velocity, and electric field respectively [1]. In the above equations, D is the gap separation between the plates, ω is the RF electric-field frequency, e is the electron charge, and m is the electron mass.

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† msiddiqi@umd.edu

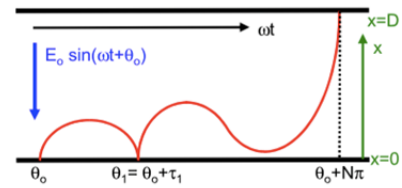

Figure1: Particle orbits in a period-2 ping-pong multipactor [1].

SIMULATION OF PING-PONG MODES

To test the ping-pong theory, we set up a 3D Simulation using the the WARP particle-in-cell code. WARP uses the POSINT library to model SEE, which includes detailed SEE parameters for any given material [1]. For the simulations, unbaked-copper surfaces are chosen, which has a peak SEE yield of of 2.1 occurring at an electron impact energy of 271 eV [1]. Additionally, the code assumes a velocity distribution consistent with experimental measurements. The geometry consists of two parallel plates (0.125 mm thick, 23 x 23 mm wide) separated by a distance D, which is varied throughout the simulation. A gap impedance of 50 ohms is assumed [1]. An RF sinusoidal electric-field is present between the gap with a frequency of 0.5 GHz.

Initial simulations uniformly seed the particles between the gap prior to the start of the simulation. A series of simulations are run in a gap range of 0.75 mm – 15.0 mm by varying $\overline{v_0}$ for a fixed material and fixed RF electric-field frequency. The simulations are run for 5 RF periods, which is sufficient to indicate multipactor growth or decay [1]. For each gap, the simulations scan the electric-field strength and then interpolates the results to find fields that give unity gain [1]. The results of the simulation scan are shown in Figure 2. The simulation and upper period-2 ping-pong cutoff bound agree nicely for intermediate normalized velocities in the range [0.1,0.2]. However, for small and large normalized velocities, corresponding to large and small gap heights respectively, a discrepancy is seen between the upper cutoff bound and the simulation [1].

To better understand this discrepancy, a new electron seeding method is introduced where electrons are continuously injected over one RF period. This is in contrast to the uniform seeding method used in the initial simulations, where the seed electrons are placed in the gap prior to the start of the electric-field. For this new seeding method, electrons are seeded every fourth time step during the first RF period. The number of seed electrons injected per time step is chosen to ensure that the total density of seed electrons by the end of the simulations equate for the two seeding mechanisms.

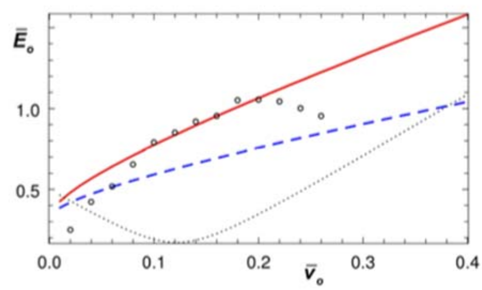

Figure 2: The upper cutoff bounds for period-1 ping-pong (blue-dashed) and period-2 ping-pong (red solid) compared to WARP Simulations (circles) for uniform seeding. The black dotted line is the lower limit for unbaked copper [1].

As done in the uniform seeding case, a series of simulations are run for a range of gap heights and the electric field strengths are scanned for the same RF frequency (0.5 GHz) and material (unbaked copper). Figure 3 shows the results of the continuous seeding scan in comparison to the uniform seeding scan and the theoretical upper cutoff bounds. As indicated by the x's and o's completely matching on top of one another, the continuous seeding mechanism does not mitigate the discrepancy seen between the uniform seeding mechanism and the theoretical upper cutoff.

Although this was not in line with our expectations, we found that the simulation points were able to become closer to the theoretical upper bound by increasing the power between the gap, which can be expressed in terms of the gap impedance (50 ohms). Figure 4 depicts two uniform electron seeding simulation scans done in different power ranges. The powers run in the second simulation scan (blue circles) are done in a ten percent higher power range than the first simulation scan (red circles). As shown in the plot, all the simulation points for the higher scan moved up and even exceeded the upper cut off bound for certain gap heights. Additionally, the simulation plots out trajectories for different power ranges.

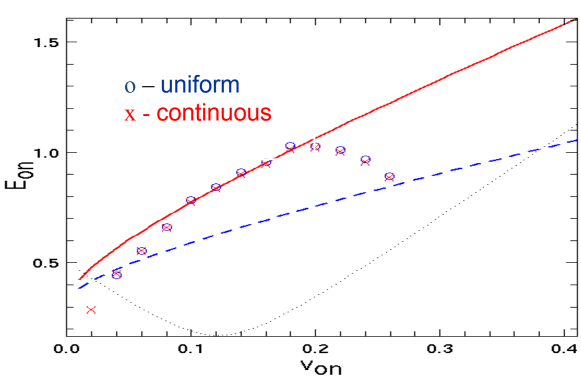

Figure 3. Warp Simulations of the upper cutoff bound for uniform seeding (blue circles) and continuous seeding (red crosses).

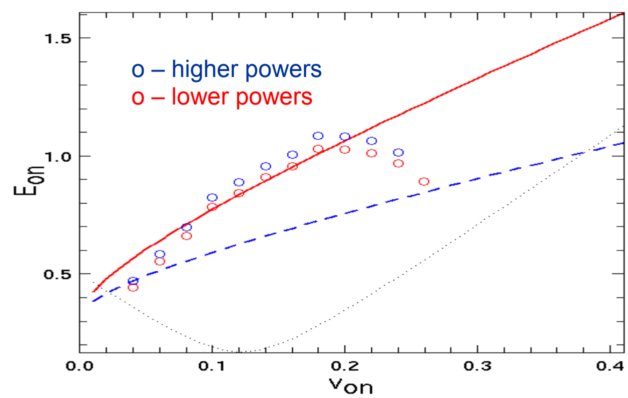

Figure 4: WARP simulations of the upper cutoff bound done for uniform seeding with different power ranges (blue and red circles).

MULTIPACTOR MAPS

Higher order ping-pong modes are much more difficult to analyse. Here, we use concepts from non-linear dynamics to analyse higher-order periodicity multipactor, specifically the usage of discrete-time maps. Since the impact energy and the SEE yield are completely determined by emission and arrival phases of the secondaries, a map can be constructed relating arrival phase to launch phase for any given emission phase and velocity spread [1]. By iterating the maps to advance the particles, the attractor of the system can be found. From this, the SEE yield for each initial phase can be determined. Note this method does not make any use of the geometry. Thus, this analysis can be generalized to any device. Additionally, this approach can identify multipacting region boundaries more comprehensively compared to traditional models [1]. This technique is global because it is capable of analysis of many types of multipactor [1].

CONCLUSIONS

Ping-pong multipactor combines single-surface and two-surface impacts and has a resonance condition that the total transit time for all impacts in one period must be N (odd) half periods. Initial simulations that seeded electrons uniformly between the gap and prior to the start of the RF electric-field agrees with the upper period-2 ping-pong cut off bound for only intermediate gap heights. A new seeding method of continuous injection does not mitigate the discrepancy seen for small and large gap heights. However, it was discovered that the simulation had a stronger dependence on the power between the gap. The simulation points for the small and large gap heights that are run in a higher power range moved closer to the theoretical curve. This result is consistent for both seeding mechanisms that were tested.

Moreover, a new-map based method is introduced for analysing higher-order multipactor. This analysis does not depend on the geometry of the device and thus can extend to any application. This global perspective on multipactor overcomes major obstacles faced by conventional models. Preliminary simulations have been done which will serve as a basis for future work [1].

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REFERENCES

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